Viewing

LP-A: Display Characteristics of In-Plane-Switching (IPS) LCDs and a Wide-Viewing-Angle 14.5-in. IPS TFT-LCD

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Abstract

Display characteristics of in-plane-switching (IPS) LCDs with nematic LCs of positive and negative dielectric anisotropy have been studied, in terms of their cell optimization for the wider-viewing-angle performance, higher contrast ratio, faster response time, lower operating voltage, and so on. Based on these studies, a practically unlimited viewing-angle 14.5-in. IPS a-Si TFT-LCD has been developed, which has the XGA (1024×RGB×768 pixels) resolution and 64 gray scales (262,144 display colors) capability.

1. Introduction

The larger display-area and higher display-quality are demanded for an LCD, the more sophisticated solution is required for the problem of poor viewing-angle characteristics with an LCD. An in-plane-switching (IPS) LCD [1,2] has recently been revived and expected to be the most promising among many candidates for improving the viewing-angle characteristics [3,4], including LCDs based on the multi-domain [5], optically compensating [6], collimated back-lighting [7] modes, etc. The reason is that an IPS LCD has a big potentiality for such an authentic wide-viewing-angle performance as to show a high contrast ratio as well as no inversion of gray scales.

In this paper, studies on display characteristics of IPS LCDs with nematic LCs of positive and negative dielectric anisotropy are presented, with emphasis on their cell optimization for bringing out the potentially authentic wide-viewing-angle display performance. In addition, a practically unlimited viewing-angle 14.5-in. color IPS a-Si TFT-LCD developed based on these studies is reported.

2. Structure and Electro-Optical Effect of an IPS LCD

2.1 Basic structure of a simple IPS LCD

Figure 1 shows schematically the basic structure of a simple IPS LCD used in the cell-optimization for improving the display characteristics. Interdigital metal-electrodes like a comb-shape are formed on one substrate and the opposed substrate has no electrode. This electrode arrangement produces an electric field parallel to the substrate, namely an in-plane electric field.

In case of a negative-dielectric-anisotropic nematic

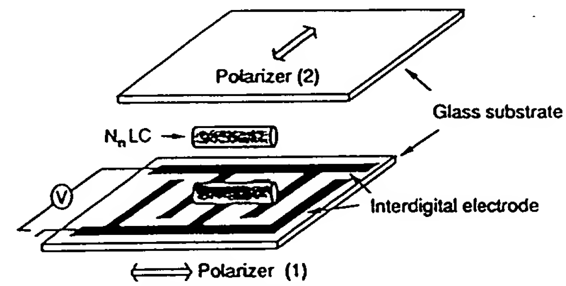
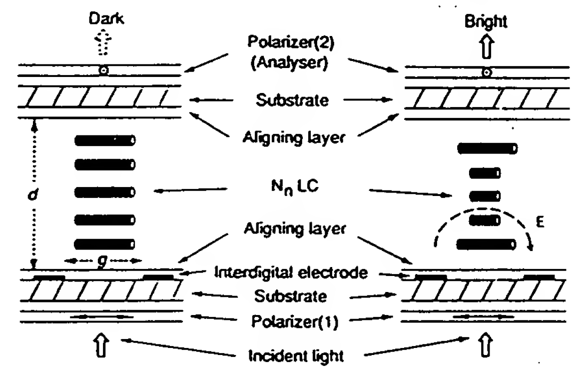


Fig. 1 Basic structure of a simple IPS LCD.



(a) Off-state (V=0) (b) On-state (V>V_{th})

Fig. 2 Operating principle of an IPS LCD.

(Nn) LC, LC molecules are aligned perpendicular to the electrodes, as shown in Fig.1, while in case of a positive nematic (Np) LC, LC molecules are aligned parallel to the electrodes. The IPS LCD is sandwiched between crossed polarizers with the LC molecules (optical axes) parallel or perpendicular to the polarization axis.

2.2 Electro-optical effect of an IPS LCD

Figure 2 presents the operating principle of an IPS LCD with an Nn LC. In the off-state of Fig. 2(a), linearly-polarized incident light from the polarizer (1) can not pass the polarizer (2) (analyzer), and the LCD appears dark. On the other hand, in the on-state with an applied voltage V above the threshold, as shown in Fig. 2(b), the incident light is transmitted through the analyzer, since LC molecules are rotated in the plane parallel to the substrate and their optical axes deviate from the polarization axis by the angle θ (V).

The above light transmission is caused by an electric field-induced phase retardation. Therefore, the transmission intensity may be determined by the following equation:

$$I = I_0 \sin^2 2\theta(V) \cdot \sin^2 (\pi \cdot \Delta nd / \lambda) \quad , \qquad (1)$$

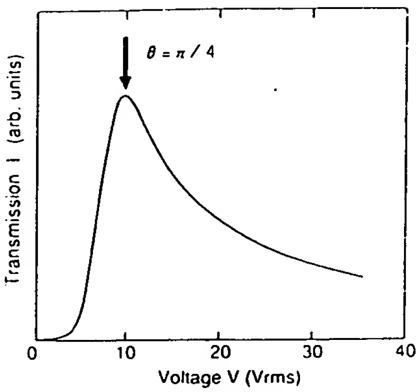


Fig. 3 Electro-optical response of a simple IPS LCD.

where Δn is the birefringence of an LC, d is the LC cell thickness, and λ is the wavelength of incident light. This equation predicts that a maximum transmission is obtained at V, which induces the deviation angle $\theta(V) = \pi/4$.

Figure 3. shows the electro-optical response curve observed for an IPS LCD filled with an Nn LC mixture ZLI-2857 (Merck) with $\Delta\varepsilon = -1.50$ and $\Delta n = 0.0743$. The cell thickness d and electrode gap g denoted in Fig. 2 were 6µm and 5µm, respectively. The transmission intensity of incident white light increases with increasing V, reaches the maximum value at V=9.8V, and then decreases gradually, as predicted above.

The deviation angle θ (V) was measured by using a polarizing microscope. As indicated in Fig. 3, V=9.8V giving the maximum transmission induced $\theta(V) = \pi/4$. This supports the validity of Eq. (1) for use in the cell optimization of an IPS LCD. Accordingly, Eq. (1) may also suggest that adjustment of the cell retardation $\Delta n \times d$ to a half of the incident wavelength is basically essential to realize a higher contrast and more achromatic black & white display with an IPS LCD.

3. Display Characteristics of Simple IPS LCDs

3.1 Viewing-angle characteristics

An IPS LCD exhibits in principle the much wider viewing-angle characteristics, compared to a conventional TN LCD, since LC molecules in an IPS LCD are rotated in the plane parallel to the substrate in the on-state. Nevertheless, as demonstrated in Figure 4, the viewing-angle characteristics are strongly influenced by the pretilt θ of LC molecules to the substrate. Fig. 4 presents the iso-contrast charts with the azimuthal (Φ) and zenithal (Θ) viewing angles for two kinds of IPS LCDs with different pretilts. An IPS LCD with the low pretilt (θ=0.8°) for Fig. 4(a) is just the same one as the IPS LCD with an Nn LC used for Fig. 3, and an IPS LCD for Fig. 4(b) is also the same but with the different and higher pretilt (θ=6.5°). The low and high pretilts were obtained by applying different aligning layers of polyimide.

The comparison between Figs. 4(a) and (b) clearly indicates that the low-pretilted IPS LCD has the much

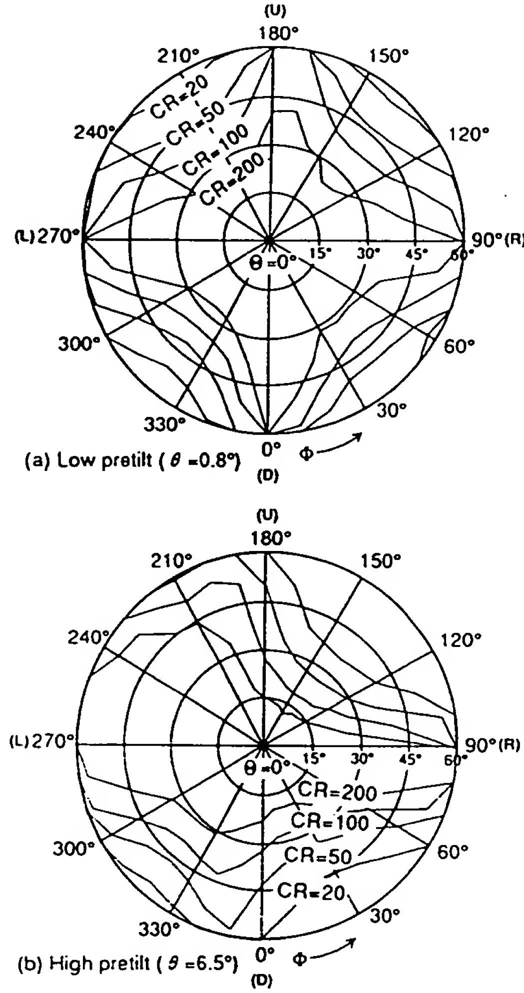


Fig. 4 Iso-contrast charts for differently pretilted simple IPS LCDs.

wider and more symmetrical viewing-angle characteristics with the contrast, compared to the high-pretilted one. In case of the high-pretilted IPS LCD, the viewing angle for each contrast becomes extremely narrow in the up (U) and down (D) viewing direction, although such dose not in the right (R) and left (L) viewing direction. The narrow viewing-angle direction was confirmed to correspond to the normal to the optical axis of LC molecules.

The above-described influence of the pretilt in an IPS LCD with an Nn LC were quite similarly observed also for an IPS LCD with an Np LC. Therefore, an optimal adjustment of the pretilt is essential in order to bring out the widest possible viewing-angle display performance of an IPS LCD.

3.2 Response times and operating voltage

(a) **Cell-thickness dependence** Figure 5 presents the cell-thickness dependence of the operating voltage Vop and of the response times ton, toff for an IPS LCD with an Np LC. Vop is defined as the applied voltage V giving the maximum transmission in the electro-optical response (See Fig. 3), and ton and toff are the on and off response

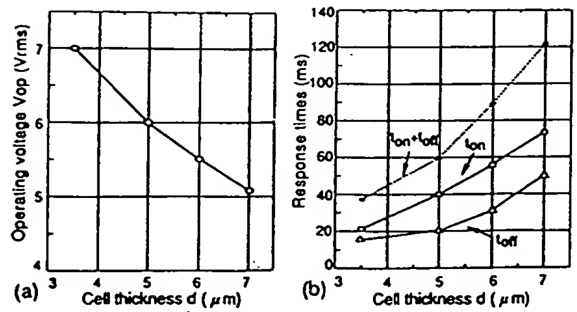


Fig. 5 Operating voltage (a) and response times (b) vs. cell thickness in a simple IPS LCD.

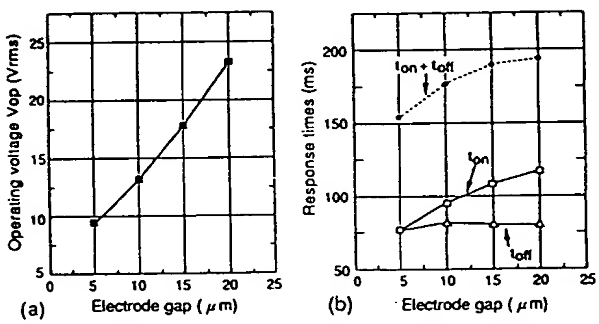


Fig. 6 Operating voltage (a) and response times (b) vs. electrode gap in a simple IPS LCD.

times at V=Vop. An LC mixture MJ-89727 (Merck) with $\Delta\varepsilon$=+4.4 and Δn=0.0791 was used as the Np LC. The low-pretilt aligning layer and g=5μm were employed. The quite similar dependence to the results of Fig. 5 was obtained also in case of an IPS LCD with an Nn LC.

Both ton and toff can be effectively decreased with decreasing the cell thickness d, as shown in Fig. 5(b), whereas, at the same time, Vop is adversely increased with decreasing d, as seen from Fig. 5(a). Thus, an IPS LCD has the trade-off relation with d between Vop and ton, toff to be practically taken into consideration. Such relation does not exist in an TN LCD. Here, it should be noted that the relation between Vop and d shown in Fig. 5(a) does not fit the theoretical equation (Vop$\propto$ 1/d) derived recently [8].

(b) **Electrode-gap dependence** Figure 6 presents the electrode-gap dependence of Vop and of ton, toff for an IPS LCD with an Nn LC. The IPS LCD used was the same one as used for Fig. 3 but with various electrode-gaps g. Vop as well as ton is favorably decreased with decreasing the electrode gap g, while toff is hardly varied with the change of g. Such quite similar results were obtained also for an IPS LCD with an Np LC. Therefore, from a viewpoint of display application, the electrode gap should be made as small as possible in an IPS LCD.

4. A 14.5-inch color IPS a-Si TFT-LCD

On the basis of the above-described studies concerning the simple IPS nematic LCDs, we have developed a 14.5-inch-diagonal color a-Si TFT active-matrix LCD employing the IPS nematic mode. Figure 7

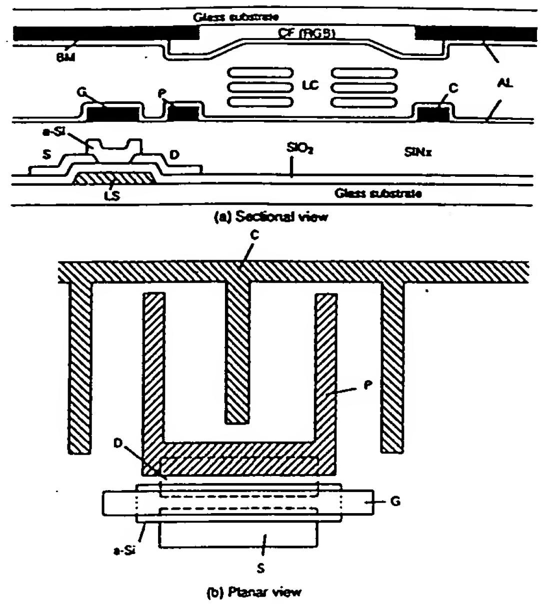


Fig. 7 Schematic structure of a 14.5-in. IPS TFT-LCD.

Table 1. Specifications of a 14.5-in. IPS TFT-LCD

Display area	14.5 inch diagonal
Number of pixels	1024(H)×RGB×768(V) (XGA)
Dot size	96 [μm]×260 [μm]
Number of colors	262,144 (64 gray scales)
Display mode	Normally black IPS nematic
Viewing angles (CR>10)	Vertical: 140° Horizontal: 140°
Contrast ratio	>100 (Max)
Driving voltage	5 [V]
Response time	60 [ms] (t_{on}+t_{off})

gives a schematic representation of the structure of the developed prototype IPS TFT-LCD, showing the sectional view in Fig. 7(a) and the planar arrangement of electrodes in Fig. 7(b). The employed a-Si TFT is of a top-gate type, and the pixel P and common C electrodes produce an in-plane electric field for switching LC molecules.

Table 1 summarizes specifications of the prototype. The number of pixels is 1024×RGB×768 corresponding to the XGA resolution, and the number of display colors is 262,144 due to the gray scales of 64. The maximum contrast ratio for the front view is more than 100, and each of the vertical and horizontal viewing-angles is around 140 degrees with the contrast ratio higher than 10. Such wide viewing-angle characteristics are distinctly shown in Figure 8 of the iso-contrast chart for the prototype.

Figure 9 shows color photos of a 64-gray-scale video image displayed with the prototype IPS TFT-LCD. The photos taken from the deeply oblique viewing-angle of 70 degrees in the four sides of up & down and right & left, indicate no inversion of gray scales and almost no color shift as well as no remarkable deterioration of contrast ratio. Figure 10 shows the RGB-color shift measured for two kinds of the prototype IPS TFT-LCDs filled with LC

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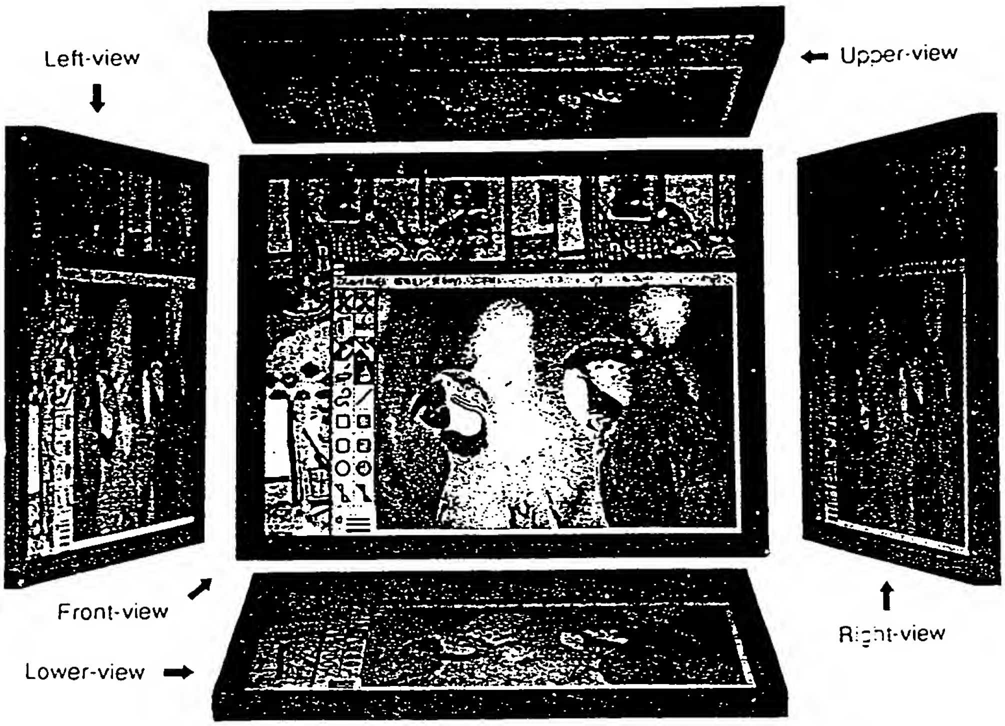

Fig. 9 Color photos of a 64-gray-scale video image displayed with a 14.5-in. IPS TFT-LCD

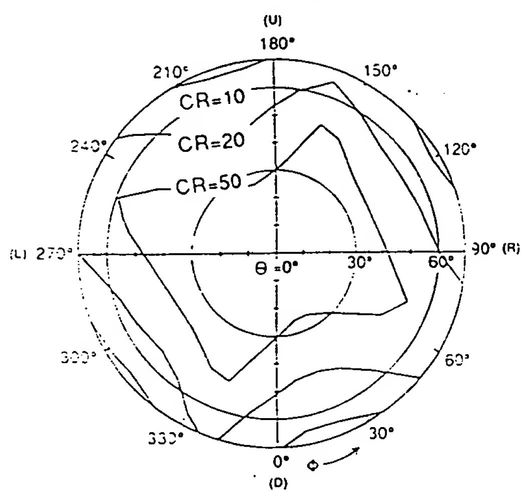

Fig. 8 Iso-contrast chart of 14.5-in. IPS TFT-LCD.

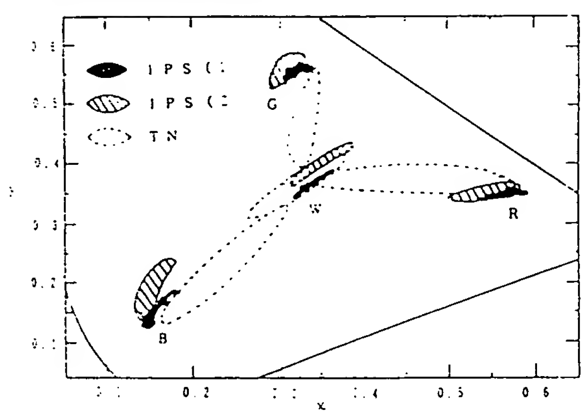

Fig. 10 RGB-color shift in a 14.5-in. IPS TFT-LCD.

mixtures with a different birefringence and for a conventional TN TFT-LCD. The color shift was measured in various azimuthal directions within the viewing cone of 140 degrees. This figure indicates that the color shift of the IPS TFT-LCD is very slight compared to that of a TN TFT-LCD. and that the shift can be further reduced by optimization of the birefringence of an LC material.

5. Conclusions

Conclusively speaking, from a viewpoint of practical applications, our developed 14.5-inch-diagonal color IPS a-Si TFT-LCD with the XGA resolution and 64 gray scales has almost no viewing-angle limitation. That means, the prototype IPS TFT-LCD has realized a practically unlimited viewing-angle performance.

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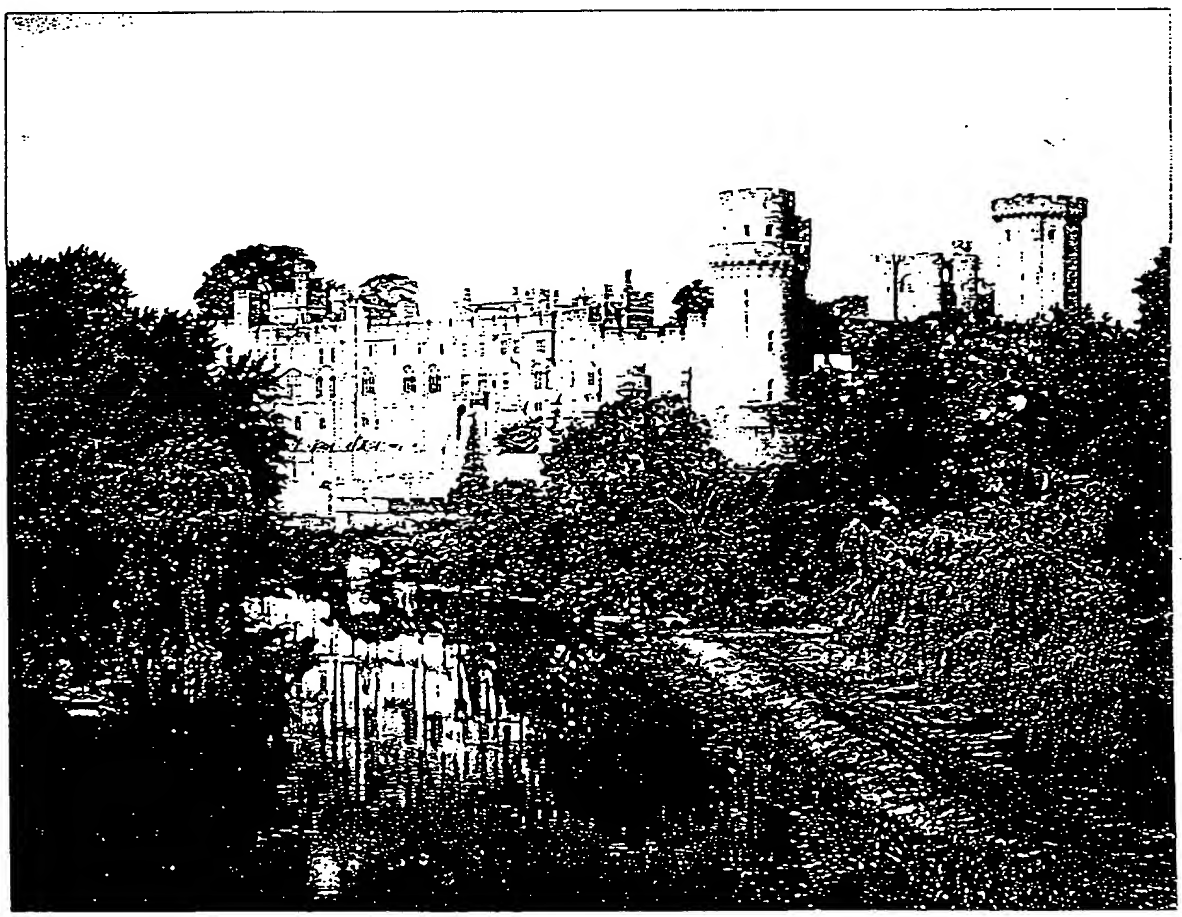

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P-51 Ferroelectric Liquid Crystal/Polymer Network For Displays (p.415)

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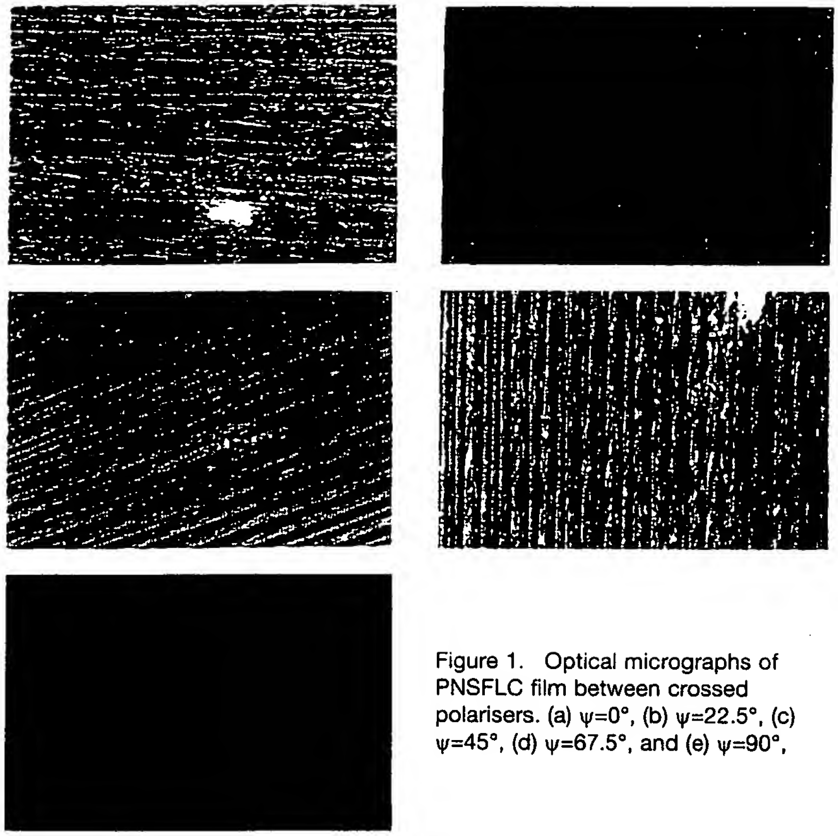

Figure 1. Optical micrographs of PNSFLC film between crossed polarisers. (a) ψ=0°, (b) ψ=22.5°, (c) ψ=45°, (d) ψ=67.5°, and (e) ψ=90°,

LP-A Display Characteristics of In-Plane-Switching (IPS) LCDs and a Wide-Viewing-Angle 14.5-in. IPS TFT-LCD (p.445)

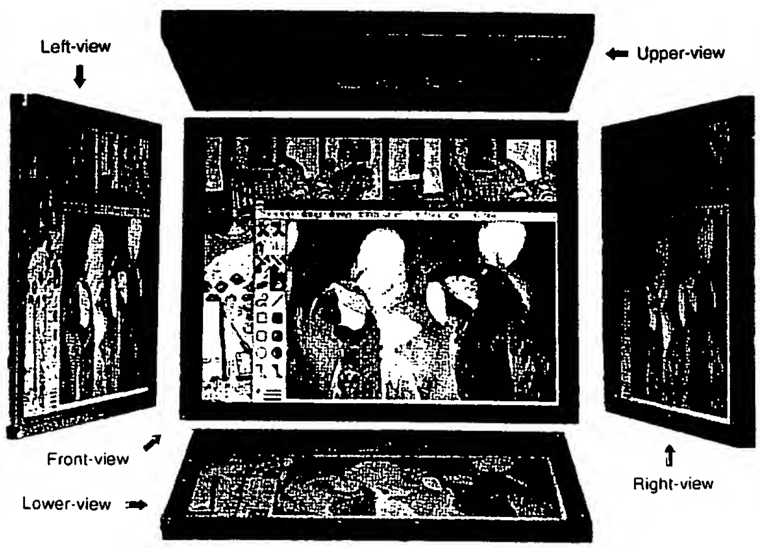

Fig. 9 Colour Photos of a 64-gray-scale video image displayed with a 14.5-in IPS TFT-LCD